The "Closed" Fountain Effect in Liquid Helium II* †

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The rise in the liquid level of a closed system of helium II through which a heat current is passing has been observed. The rise is attributed to a stress which is the difference between the thermomechanical tension given by H. London's equation, $\Delta p = \rho S \Delta T$,[1] and a Hooke's law type stress.

Fig. 1 is a diagram of the apparatus used. It consists of a glass tube which was packed with rouge powder (R) and which was surrounded by a bath of liquid helium II. Sealed to the bottom of the glass is a Kovar tube (K) into which was soldered a brass plug (B). The purpose of the glass frit (F) was to serve as a porous barrier against which the rouge could be packed. Above this frit are a heater (H) and a carbon resistance thermometer (T). At the top the system is joined to a small diameter glass tube which extends up through the helium flask.

Helium gas from an outside supply was condensed in the inner system in such an amount that the liquid level at zero heater power

in the helium II temperature range was in and near the bottom of the small diameter glass tube. The bath temperature was held constant in the liquid helium II range and the height and temperature of the liquid above the frit were observed as a function of heater power.

Fig. 2 is a typical plot of the height of the inner helium level as a function of heater power (milliwatts). As the power was increased from zero there was at first a slight decrease in level which one would expect as the density of helium II increases with increasing temperature. At a certain power (here 61 mw) the level suddenly rose and continued to rise with increasing power until the temperature of the liquid above the frit exceeded the λ-point. Here bubbling and a geyser effect took place. On decreasing the power it was found that the level was higher than on increasing power for the same value of power. However, at low powers the level returned to its original height.

The following results were found. (1) There is a linear relationship between power and temperature difference at low powers. The relationship becomes non-linear in the power region in which the level begins to rise. (2) In the region of the level rise the height is proportional to the temperature difference. (3) The level rise for a given temperature difference is much less than for the normal fountain effect.[2,3]

It might be reasoned that the rise in level follows from the formation of a gas bubble in the gaps between the rouge particles. There are two points which tend to rule out this possibility. One is that there is no drastic change in the thermal conductivity and the other

is that no bubbles were ever seen in the gap which eventually developed between the frit bottom and the top of the rouge. To eliminate the possibility that the frit was responsible for the effect and to demonstrate the necessity of the small channels in the rouge a run was made with a similar apparatus minus the rouge. The only level change observed in this case was a continual decrease in height with increasing power and temperature difference as one would expect from the density-temperature dependence.

To test the hypothesis that this effect was less than the normal thermomechanical effect because of a downward Hooke's law type tension, runs were made with the identical apparatus except that the glass tube above the frit was replaced by one of different cross sectional area. It was found then that it was more nearly the volume increase in the tube which corresponded to a given temperature difference rather than the height (or pressure).

The "difference" forces acting on a cross sectional area of the channels in the rouge are considered to be (1) a downward hydrostatic force resulting from the level rise, (2) a downward force resulting from the increase in temperature and hence an increase of vapor pressure of the liquid above the frit, (3) an upward thermomechanical force ($\rho S \Delta T$ x area) and (4) a downward force proportional to the ratio of the elevated volume to the volume of liquid in the rouge (volume strain). The first two are small compared to the last two. A "compressibility" is then calculated.

Table I is a summary of some of the data. Comparing runs 2 and 3 which were made at about the same temperature it is seen that the

TABLE I. Listing of data

Run	Bath Temperature (°K)	Tube Cross Section Area (cm^2)	Height	Slope vs Temp.Diff. $H/\Delta T$ (cm/°K)	Compressibility (atm^{-1})
1	2.001	0.128		121	0.30
2	1.950	0.128		115	0.29
3	1.946	0.398		59	0.46
4	1.821	0.128		100	0.30
5	1.817	0.398		43	0.35

value of $H/\Delta T$ is less for the run with the wider tube; the same comparison may be made for runs 4 and 5. The last column lists the calculated "compressibility." The order of magnitude is to be noted - the normal compressibility of liquid helium is approximately 1.3×10^{-2}/atm.[4] Thus this "compressibility" is about 25 times the normal compressibility.

The "open" fountain effect was measured after a hole was drilled in the brass plug; the experimental result agreed substantially with that calculated from H. London's equation.

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Further work is in progress and a detailed paper will be submitted shortly for publication.

REFERENCES

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[3] W. H. Keesom and Duyckaerts; J. H. Mellink; L. Meyer and Mellink, Physica <u>13</u> (153) (180) (197) 1947.

[4] W. H. Keesom, <u>Helium</u> (Elsevier, Amsterdam-London-New York, 1942) p.236,243

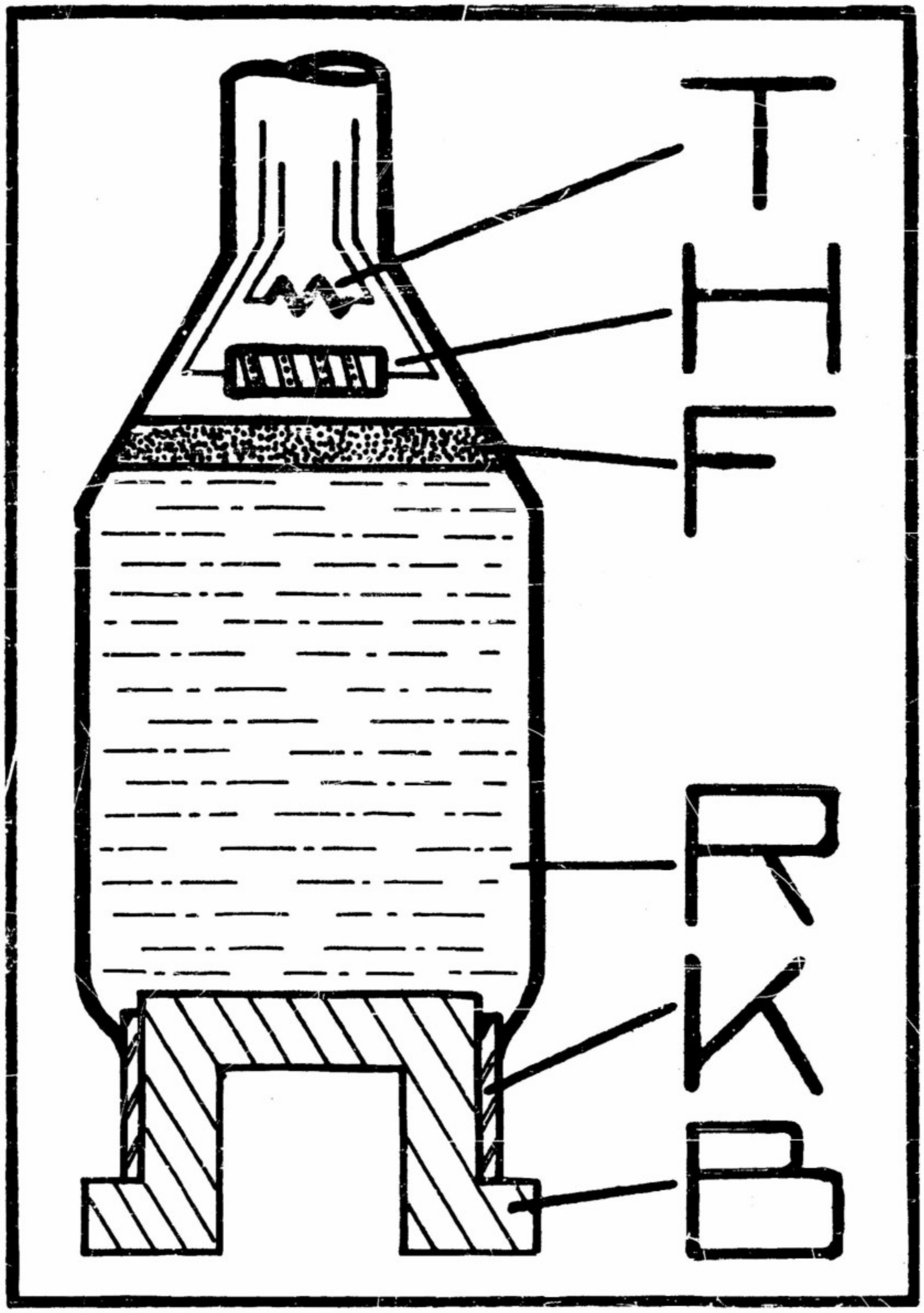

Fig. 1. Diagram of the closed, rouge-packed glass-metal system.

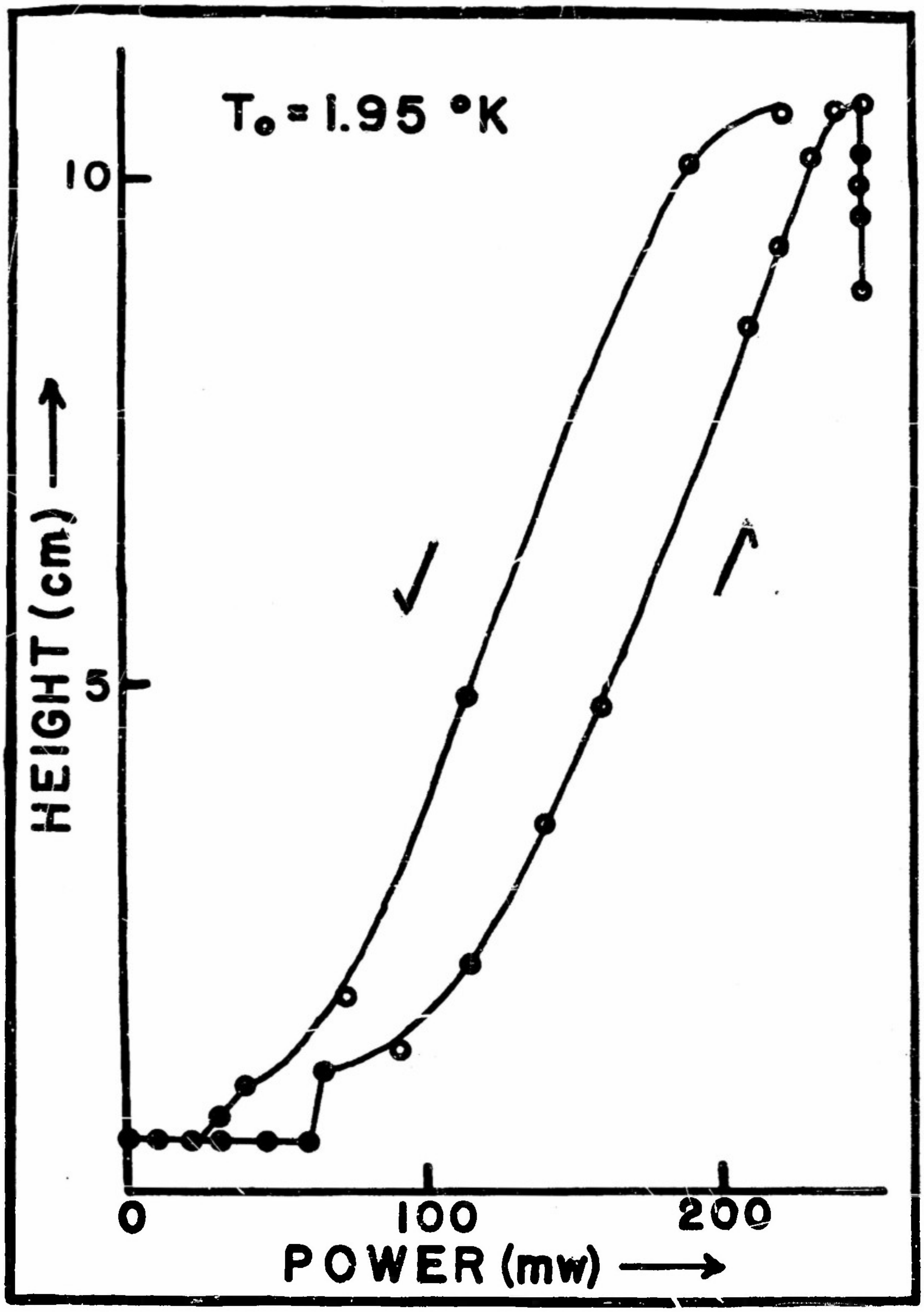

Fig. 2. Plot of the height of the inner liquid helium level above an arbitrary zero as a function of heater power input in milliwatts.

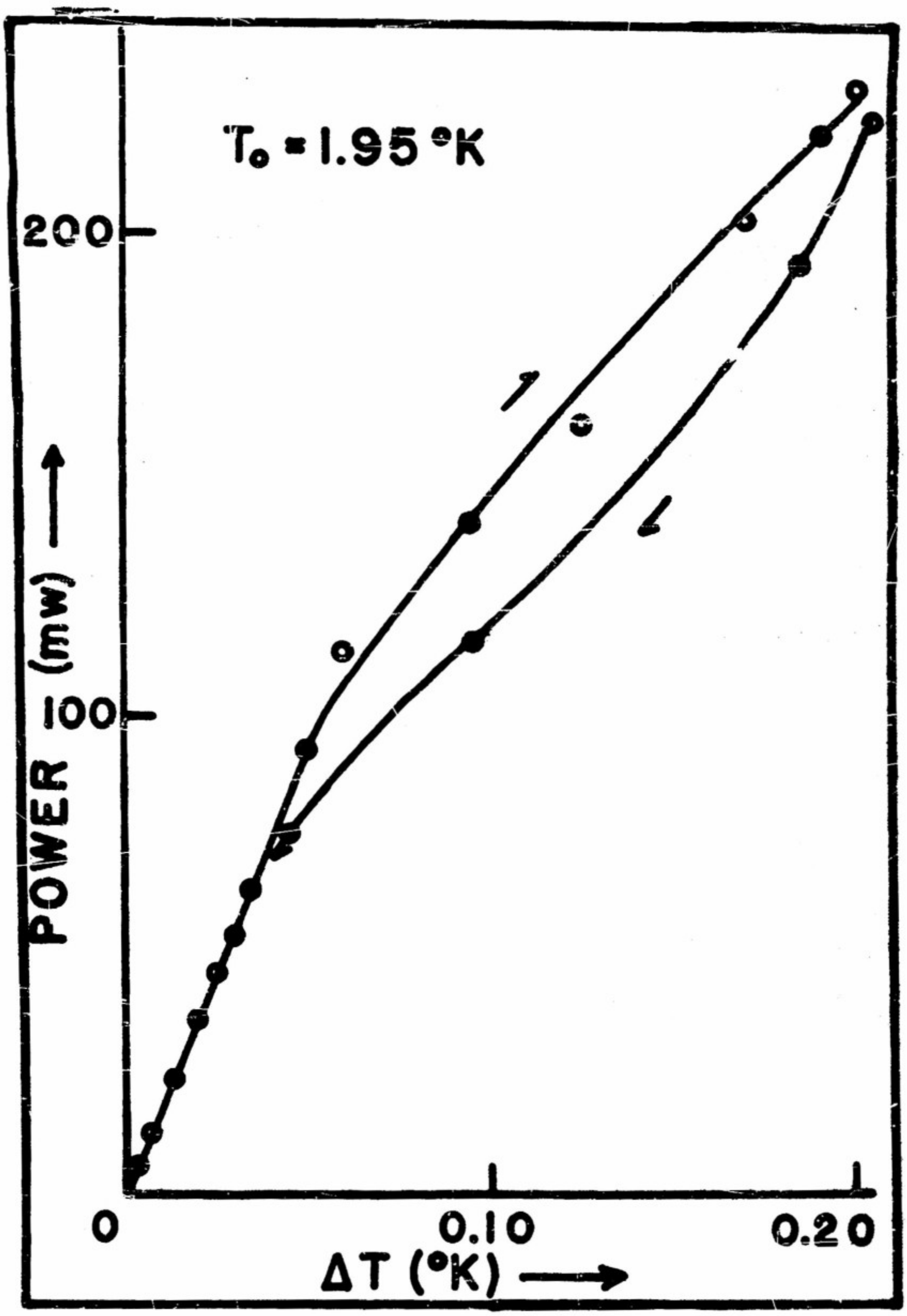

Fig. 3. Plot of heater power in milliwatts as a function of temperature difference between the liquid above the frit and the bath.

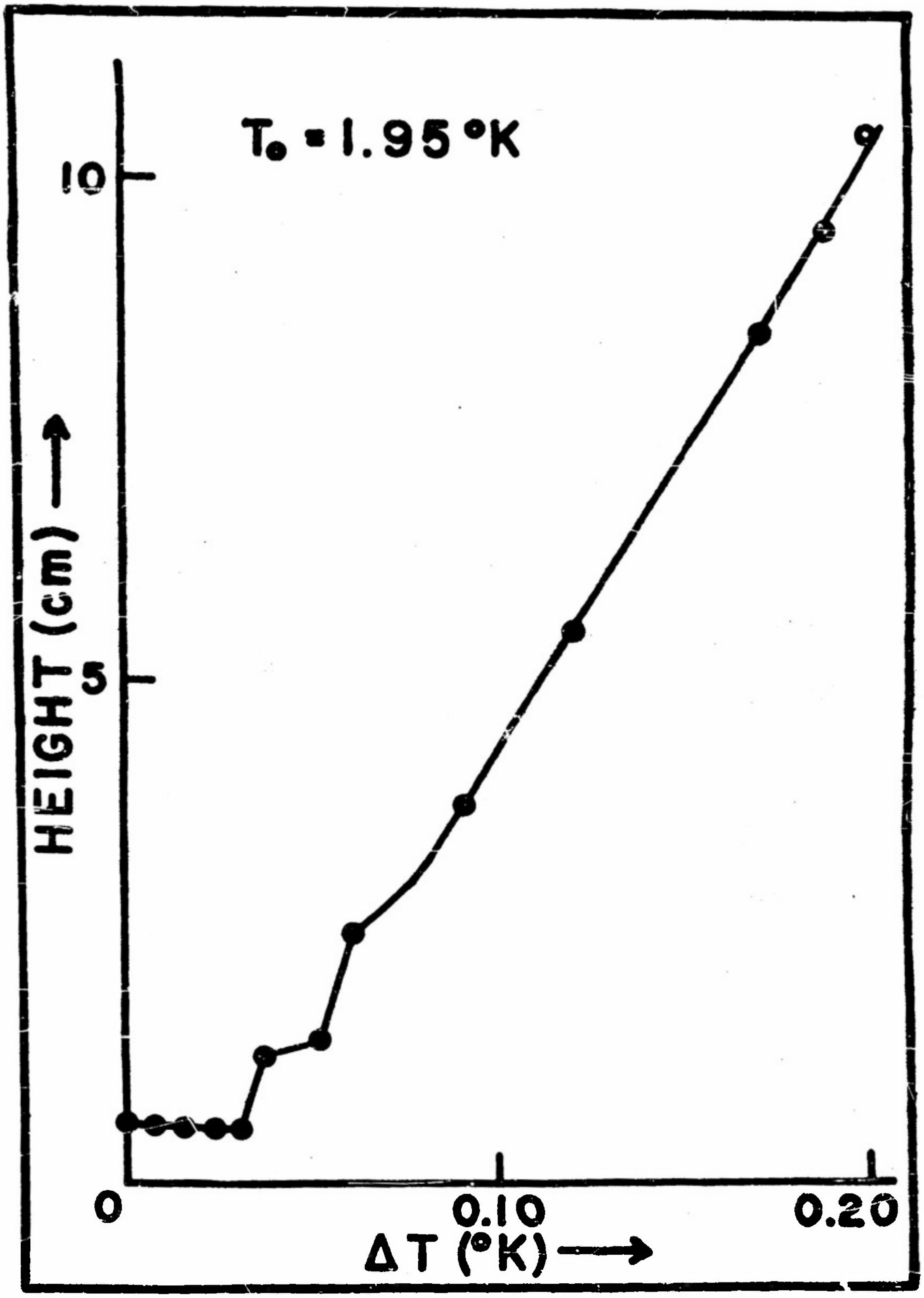

Fig. 4. Plot of the height of the inner liquid helium level as a function of temperature difference.